National Aeronautics and Space Administration

NASA Earth Science

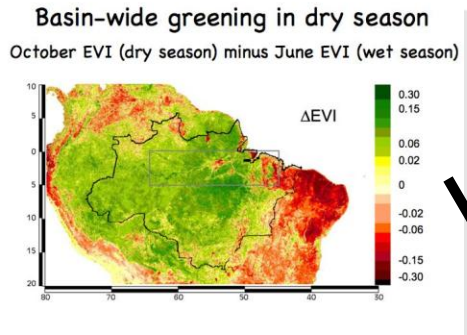
GSFC/OCT Commercial Suborbital Vehicles Workshop

7 September 2011

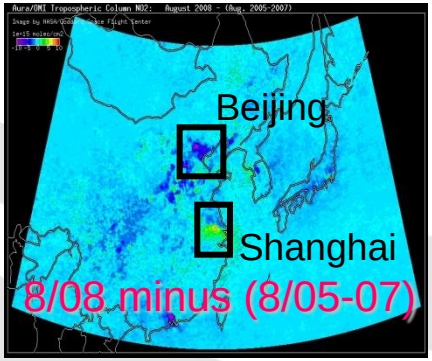
Earth Science Division Overview

- Overarching goal: to advance Earth System science, including climate studies, through spaceborne data acquisition, research and analysis, and predictive modeling
- Six major activities:
  - Building and operating Earth observing satellite missions, many with international and interagency partners
  - Making high-quality data products available to the broad science community
  - Conducting and sponsoring cutting-edge research
    - **Field campaigns to complement satellite measurements**
    - Analyses of non-NASA mission data
    - Modeling
  - Applied Science
  - **Developing technologies to improve Earth observation capabilities**
  - Education and Public Outreach

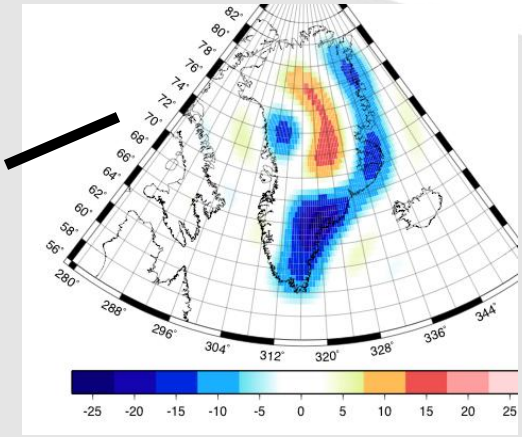
Earth **SCIENCE** Division Focus Areas



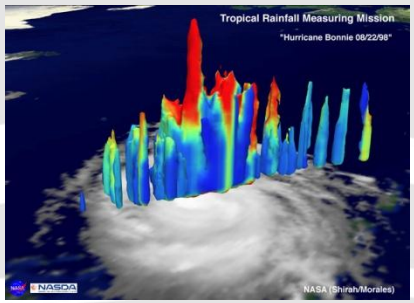
Atmospheric Composition



Carbon Cycle and Ecosystems

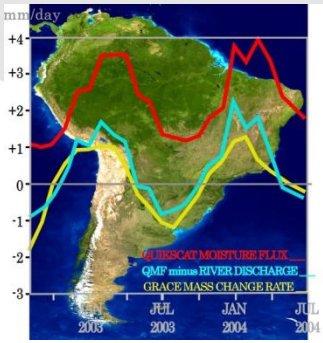


Climate Variability and Change

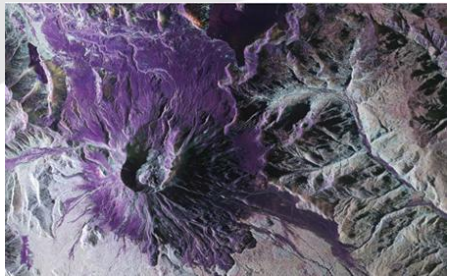


Weather

Water and Energy Cycle



Earth Surface and Interior

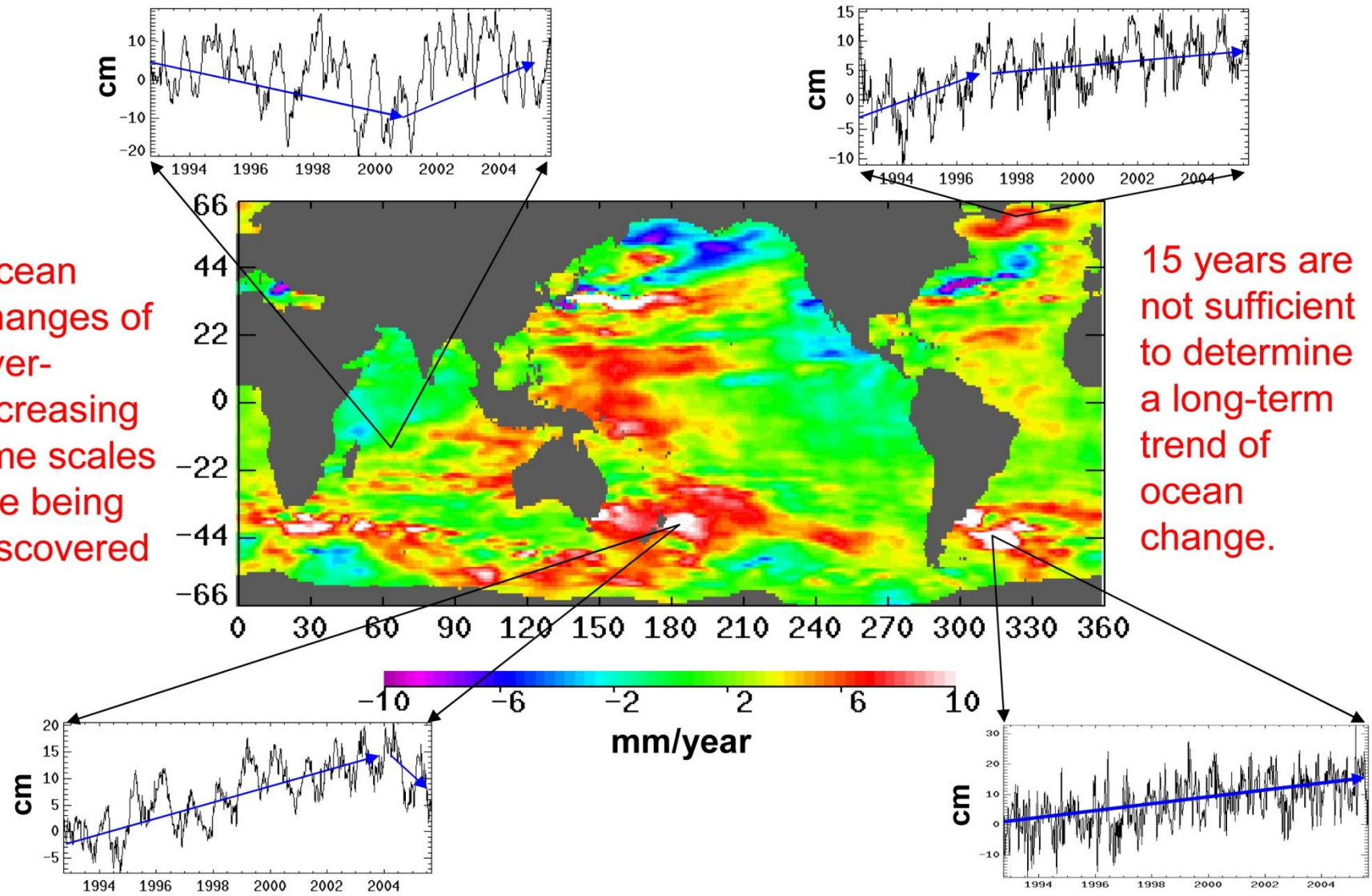


Earth System Science

- ***Earth System Science***: Requires quantitative understanding of *interactions between processes* in order to define the Earth system – nonlinearities link spatial and temporal scales

- Satellites provide stable measurements with broad coverage (global), high spatial resolution, frequent revisit; the constellation of Earth-observing satellites allows sustained measurements of many different quantities

Sea-Level Variability from Spaceborne Altimetry: The Need for Global, Multi-Decadal Measurements

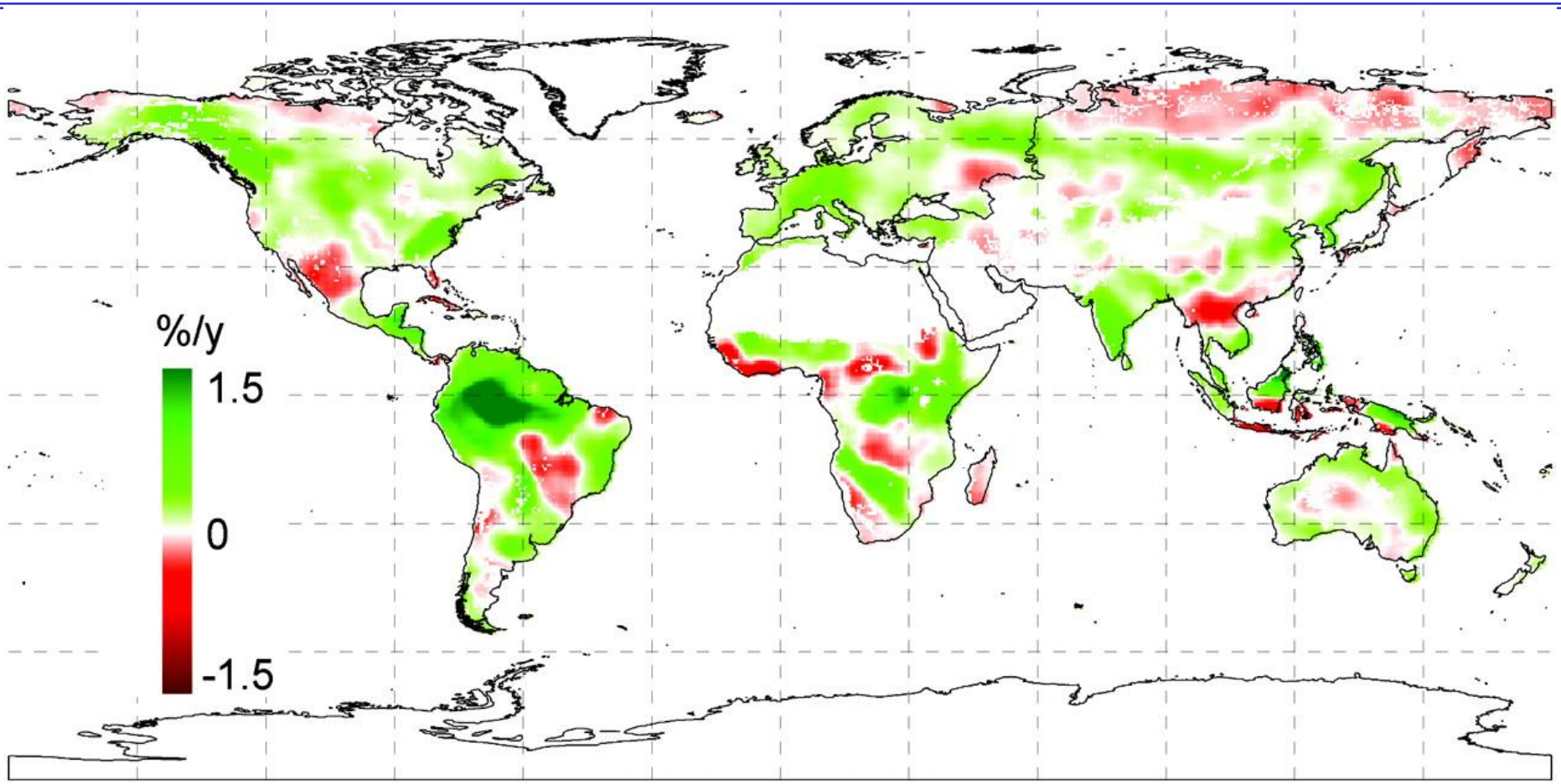


Ocean changes of ever-increasing time scales are being discovered

15 years are not sufficient to determine a long-term trend of ocean change.

Lee Fu, JPL

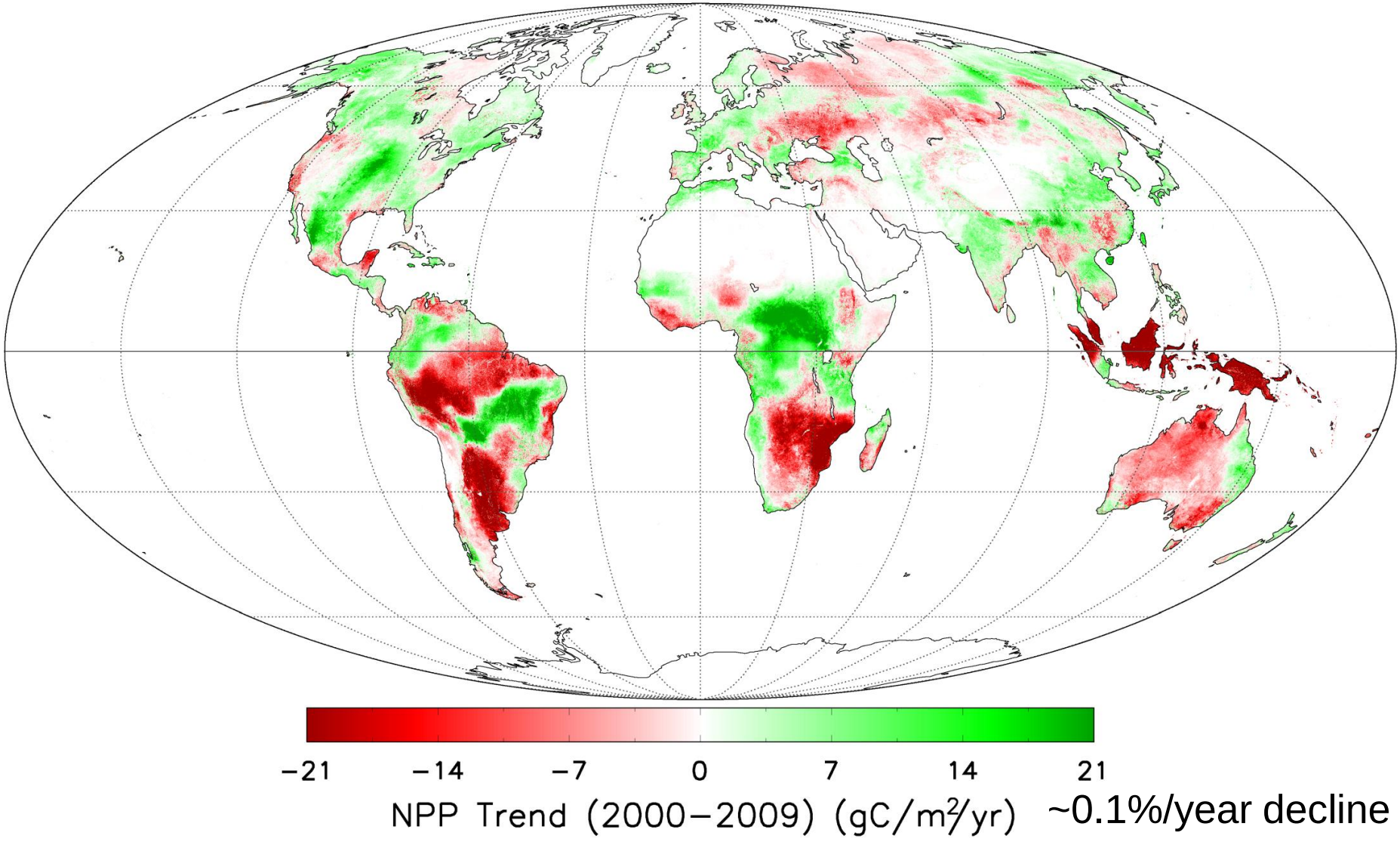
Climate change increased NPP from 1982 to 1999



AVHRR Data

Nemani et al., 2003, *Science*

Drought Decreased NPP from 2000 - 2009

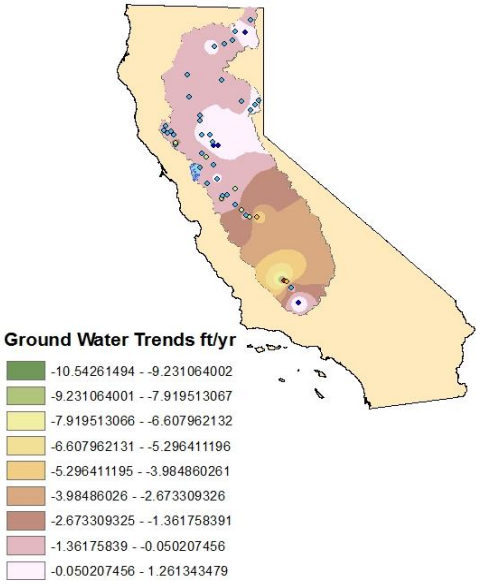


~0.1%/year decline

MODIS Data

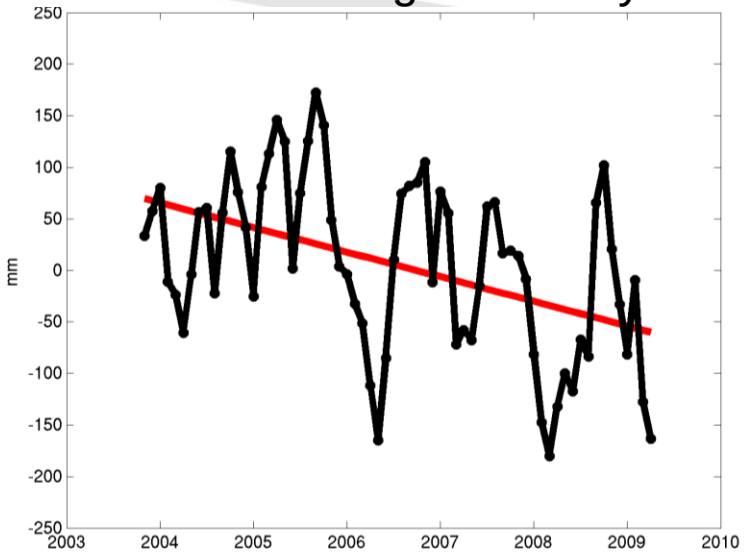
Zhao & Running 2010, *Science*

GRACE DETECTS UNSUSTAINABLE GROUNDWATER LOSS



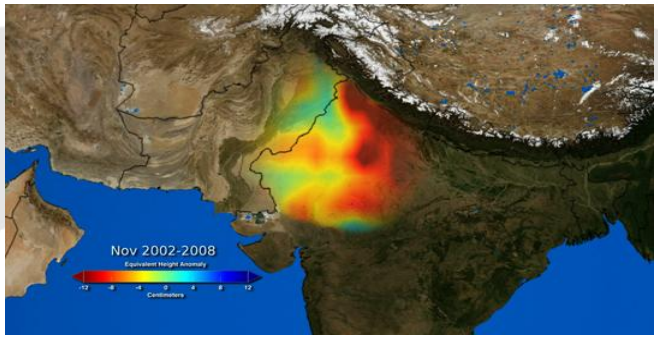
Observed trends in groundwater levels, October, 2003 – March, 2009

Water Storage Anomaly

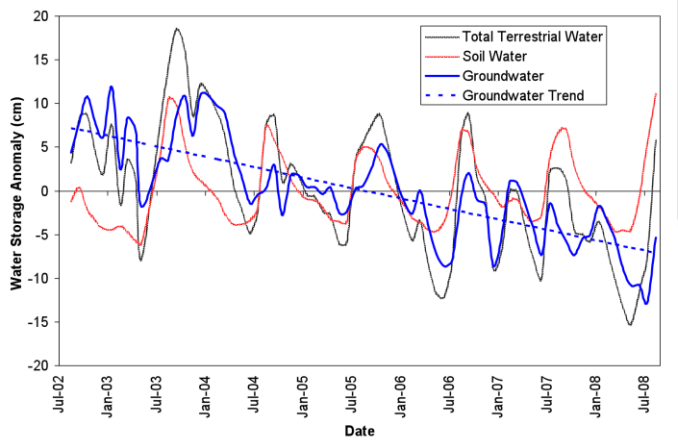


Drawdown by 31 km^3 (= 1 Lake Mead) in 66 months

Famiglietti et al., 2009



Pattern of groundwater depletion in NW India



Loss of 109 km^3 (3 Lake Meads) over 72 months

Rodell et al., 2009

Field Campaign: ICESCAPE 2010

Chukchi Sea

Sampled optically complex waters (cruise track in blue)

- Phytoplankton
- CDOM
- Some sediments

Very productive ecosystem

Phytoplankton biomass highly variable

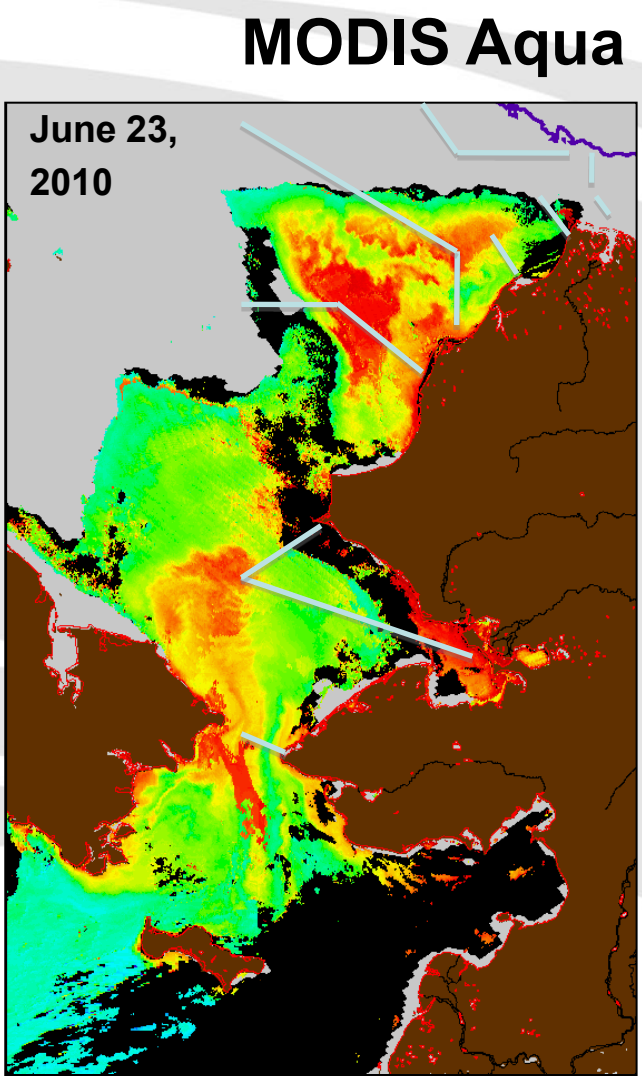
- Spatially
- Temporally

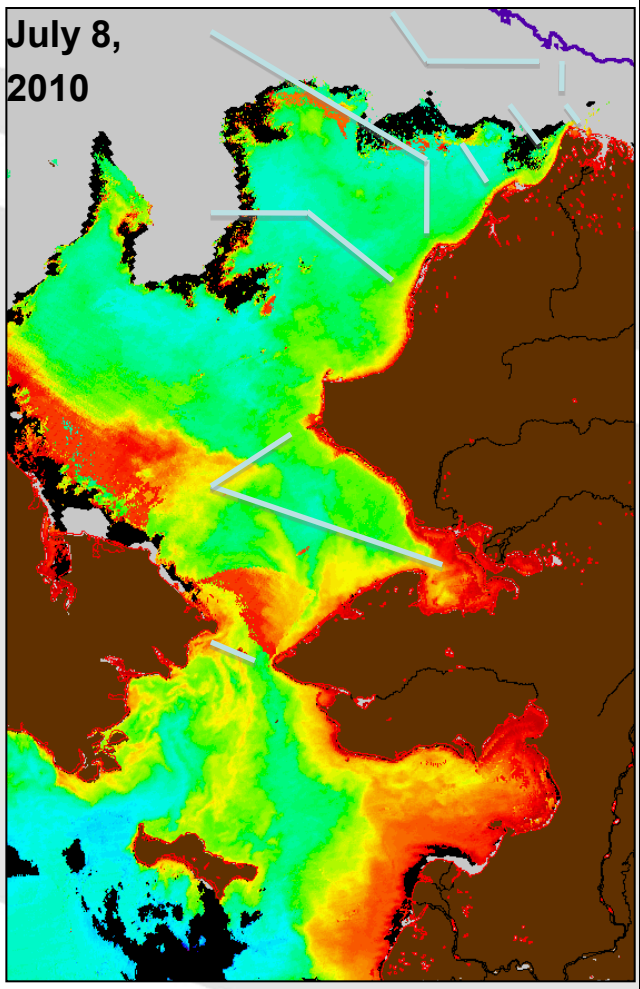
Even higher concentrations of phytoplankton just below sea surface (20-50 m)

- Among highest in world

Brown = land Gray = sea ice

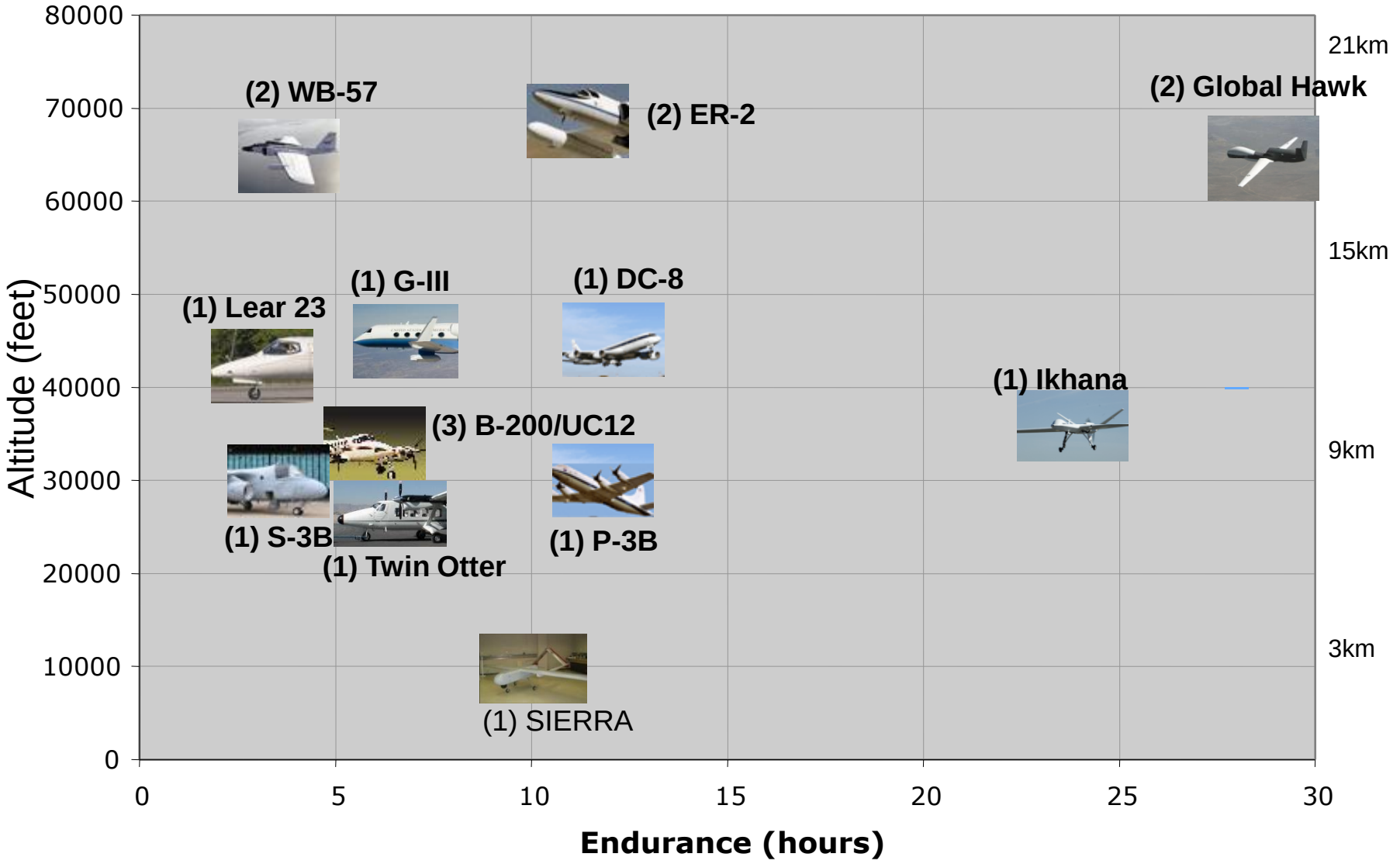
MODIS Aqua





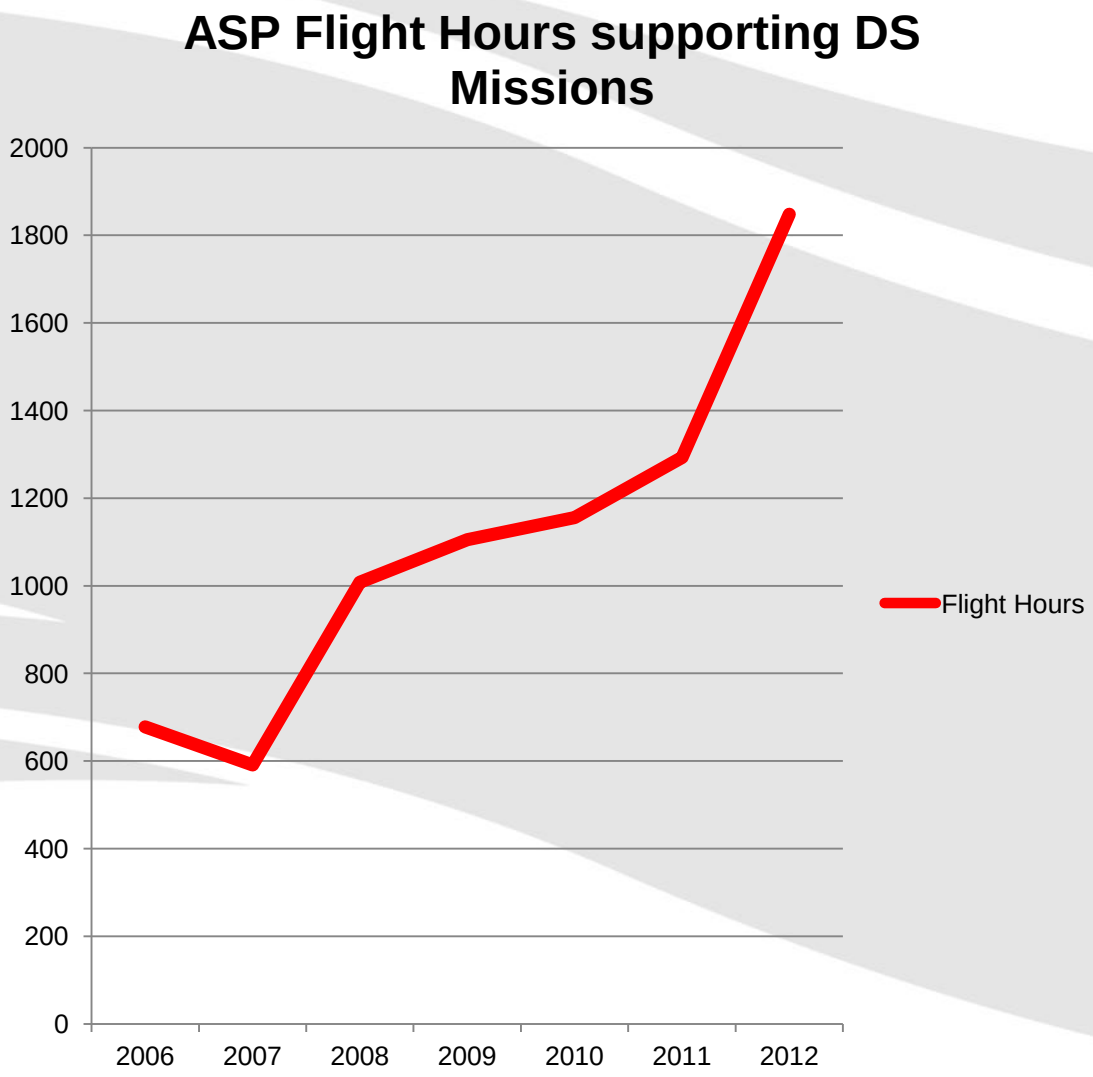
Chlorophyll *a*

NASA Airborne Science Aircraft



Airborne Science Program DS Missions

INTEX-B	2006
CC-VEX	2006
Arctic Sea Ice	2006
INTEX-B	2006
MILAGRO	2006
WRAP	2006-2009
Arctic Ice 2007	2007
CLASIC	2007
TC-4	2007
ARCTAS	2008
Calipso Caribean	2008
CASIE	2009
ASCENDS test flights	2009
Racoro	2009
GloPac	2010
ABACATE	2010
GLEAM	2010
ASCENDS test flights	2010
AID for ASCENDS	2010
SIMPL	2010
MACPEX	2011
CAR	2011
4Star	2012
DC-3	2012
HEX	2012
SEAC4RS	2012
AVIRIS CONUS	2006-2012
UAVSAR	2006-2012
CLPX II	2007-2008
SMAPVEX	2008, 2010-11
OIB	2009-2015
Earth Venture 1	2011-2014



GLOPAC

SCIENCE OBJECTIVES

- Validation of Aura/A-Train by underflights
- Observations of stratospheric trace gases in the upper troposphere and lower stratosphere from mid-lats to tropics
- Sampling of polar stratospheric air and break-up polar gyre fragments that move to lower latitudes
- Measurements of non-local dust, smoke, and pollution from Asia and Siberia
- Measurements of moist air transport from tropics to West Coast of US

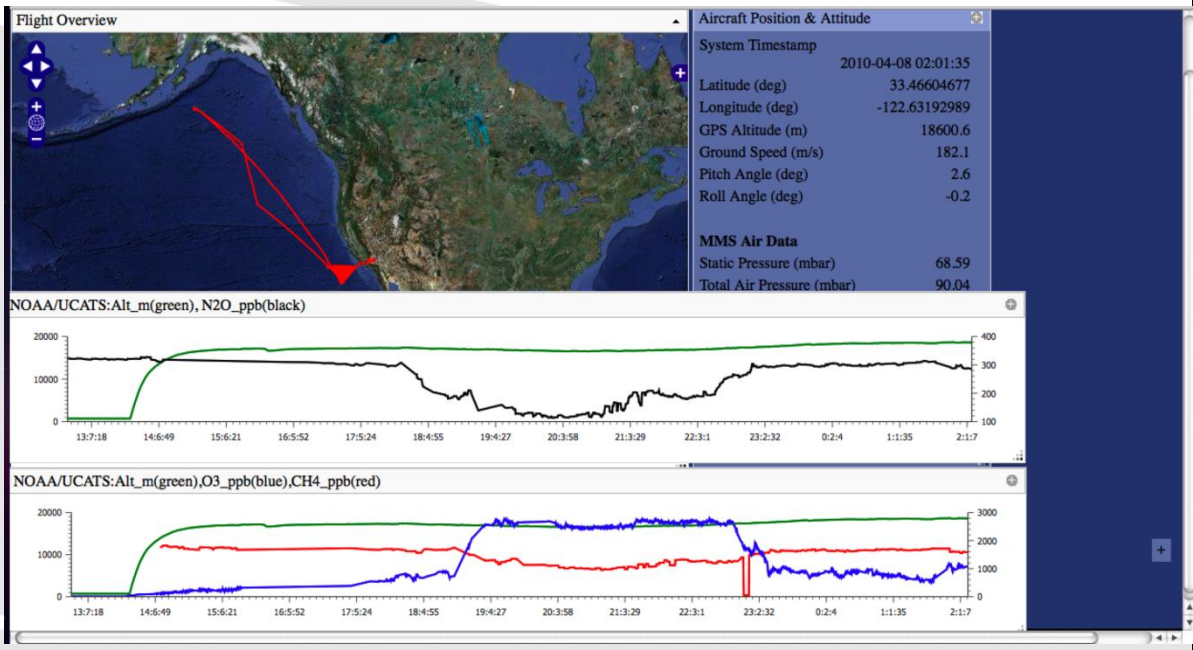
INSTRUMENTS

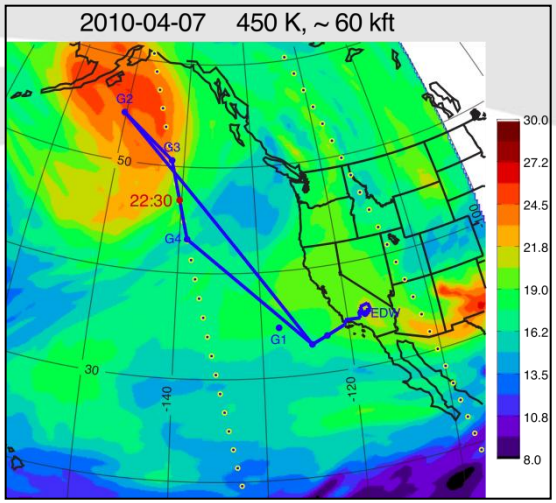
- ACAM – trace gas spectrometers, cloud camera
- CPL – cloud and aerosol LIDAR
- FACS+NMASS – aerosol spectrometers
- MMS – meteorological measurements (pressure, temp, turbulence, 3-D winds)
- MTP – microwave temperature profiler
- UHSAS – aerosol spectrometer (in situ)
- UCATS – chromatographs for trace species, ozone, water vapor
- UAS Ozone – in situ ozone analysis
- ULH – Laser hygrometer for water vapor
- HdVis – HD television for time-lapse, fish-eye video (45 deg down, forward-looking)

Unpiloted Global Hawk Completes First Science Flight Over Pacific – Wednesday, April 7

NASA and the National Oceanic and Atmospheric Administration (NOAA) have successfully completed the first science test flight of the Global Hawk unpiloted aircraft system over the Pacific Ocean. The flight was the first of five scheduled for this month's Global Hawk Pacific (GloPac) mission to study atmospheric science over the Pacific and Arctic oceans. The mission includes more than 130 researchers and technicians .

The Global Hawk can fly autonomously to altitudes above 60,000 feet -- roughly twice as high as a commercial airliner -- and as far as 11,000 nautical miles, for as long as 30 hours.

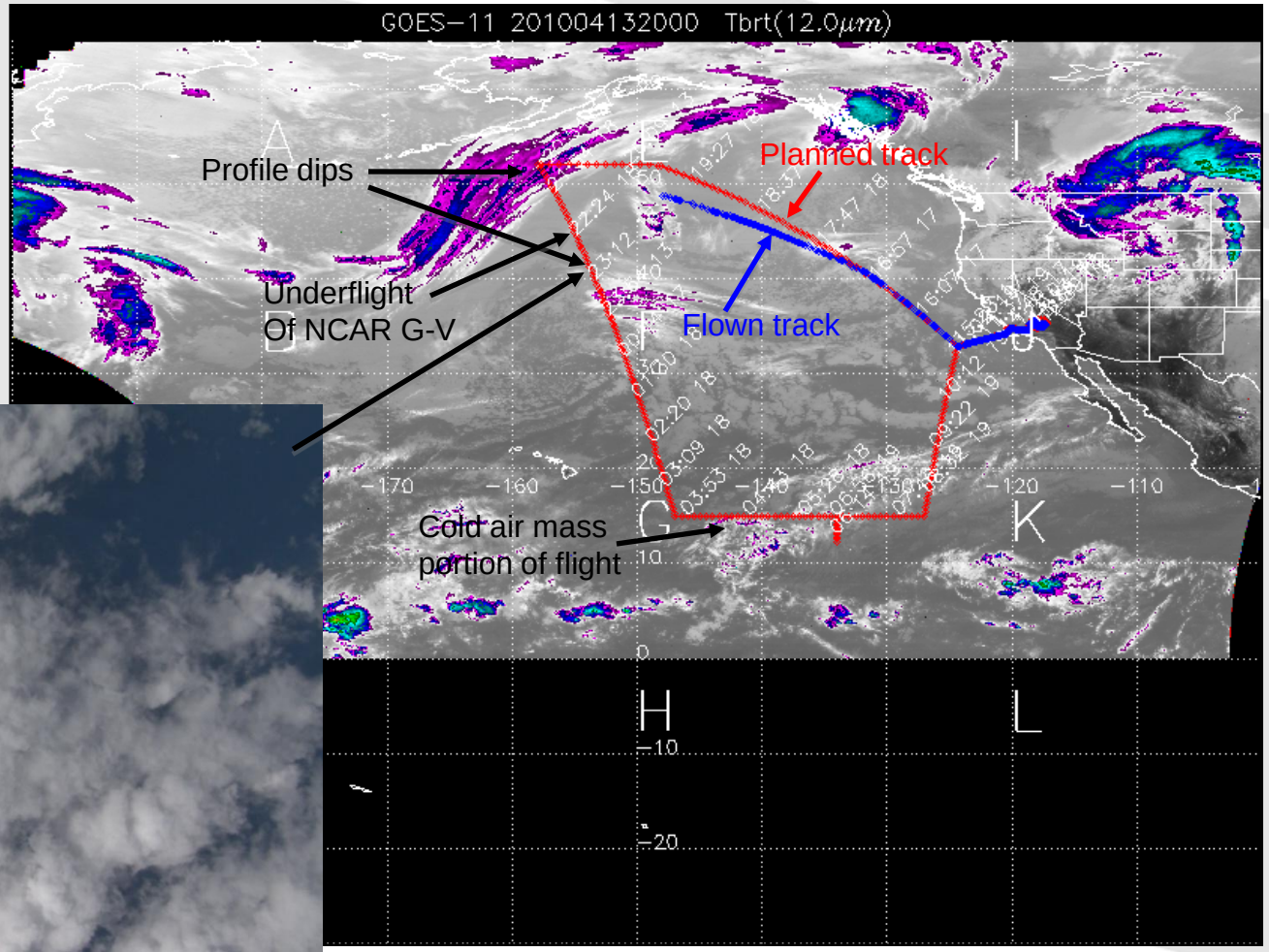




Above: The Global Hawk Operations Center (GHOC) **screen capture** shows ozone tripling (blue line) as the GH flew into the polar fragment. The red and black lines show CH4 and N2O falling. The green trace shows the aircraft altitude. The sharp increase of ozone proves that the flight intercepted the polar air fragment! (X axis is time).

Left: The blue line indicates the GH flight track. The colors represent air masses with polar (yellow-orange-red), mid-lat (green-blue), and tropical characteristics (purple-black). The small dots show the satellite sub-orbital track for Calipso. The polar fragment is the orange oval region in southern Alaska and the Gulf of Alaska.

GloPac Flight Track 2010-04-13



ACAM image at ~2333, the time of the Aura overpass. These are relatively low clouds.

IR picture. We have mostly low clouds except at northwestern end, near end of polar intrusion, and over part of south leg. Can see low clouds as well.

DISCOVER-AQ: Deployment Strategy

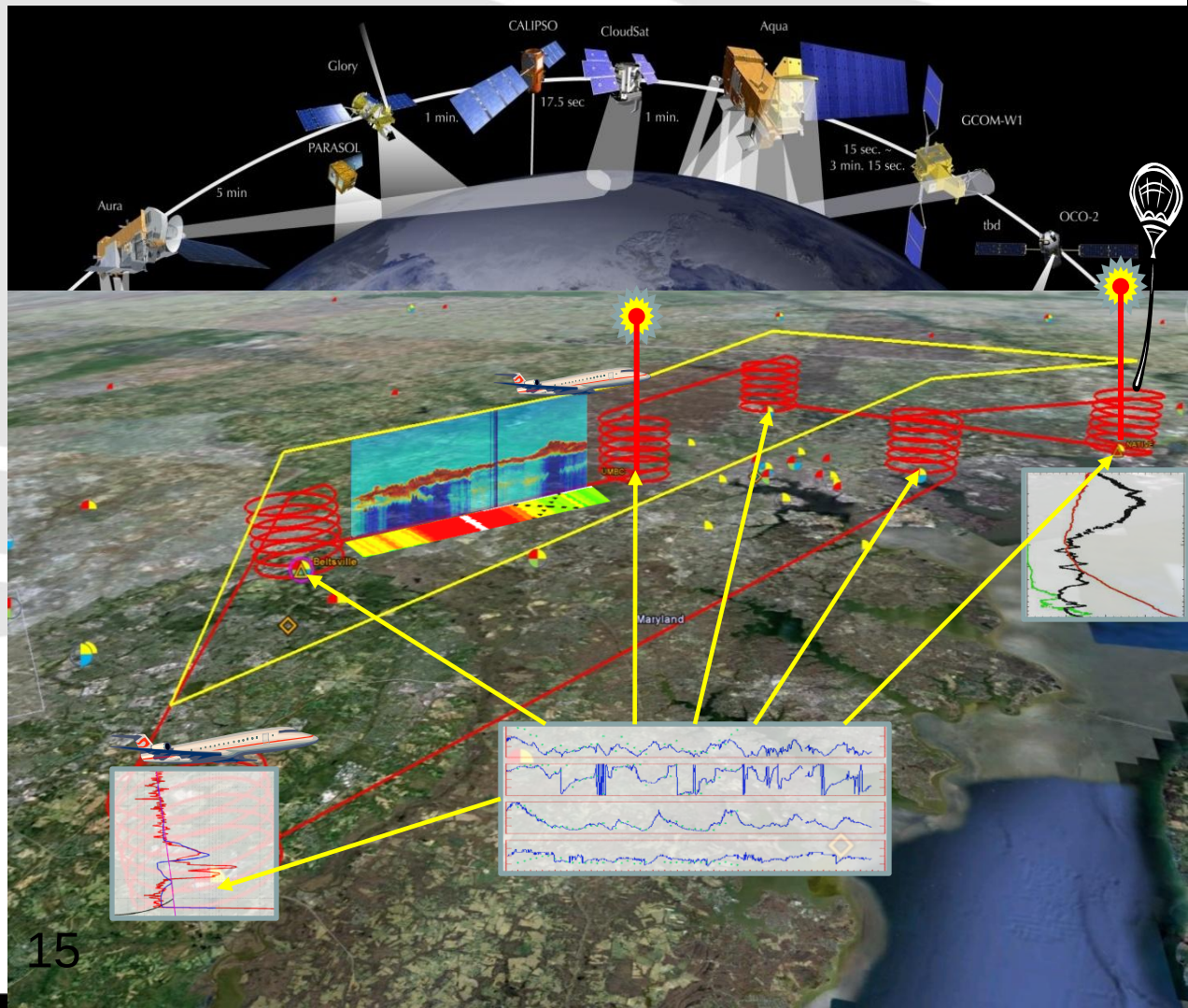
Systematic and concurrent observation of column-integrated, surface, and vertically-resolved distributions of aerosols and trace gases relevant to air quality as they evolve throughout the day.

Three major observational components:

<u>NASA UC-12 (Remote sensing)</u>
Continuous mapping of aerosols with HSRL and trace gas columns with ACAM

<u>NASA P-3B (in situ meas.)</u>
In situ profiling of aerosols and trace gases over surface measurement sites

<u>Ground sites</u>
In situ trace gases and aerosols
Remote sensing of trace gas and aerosol columns
Ozonesondes
Aerosol lidar observations

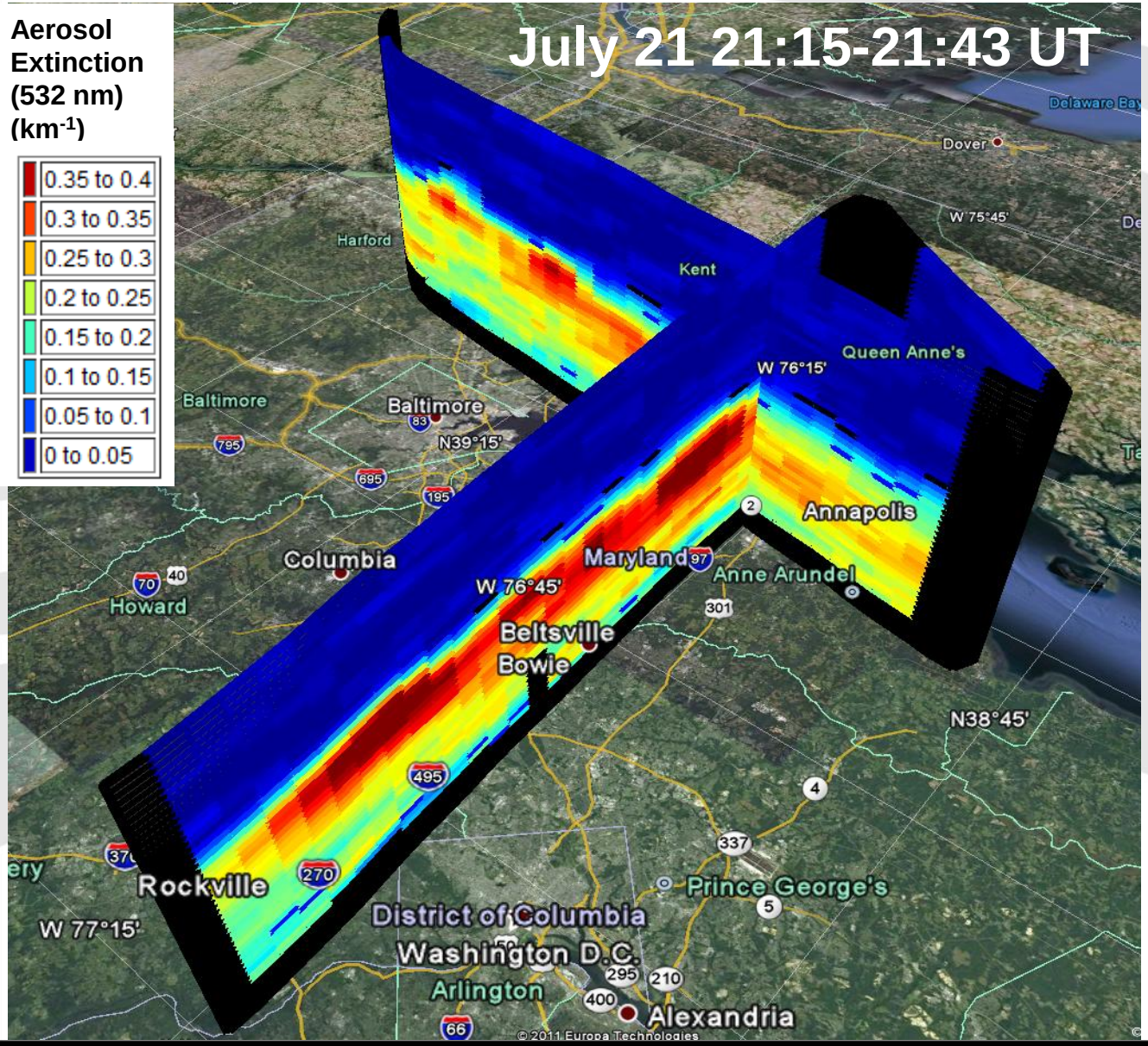


Discover-AQ Science Flights July 2011

Flight Statistics	WFF P-3B	LaRC UC-12
Sorties	14	27
Total Hours	112	106
In situ soundings over ground sites and ship	254 (~40 per site)	
Remote sensing passes over each ground site		50+
Low altitude transects over I-95/BW Pkwy	47	
Remote sensing passes over the Chesapeake Bay		50+

Flight Conditions	Number of Flight Days
AM/PM	3/11
Weekday/Weekend	11/3
Clean/Moderate/Polluted	5/4/5
TES Special Observations/MISR overpass	2/3
NOAA ship in Chesapeake Bay	4

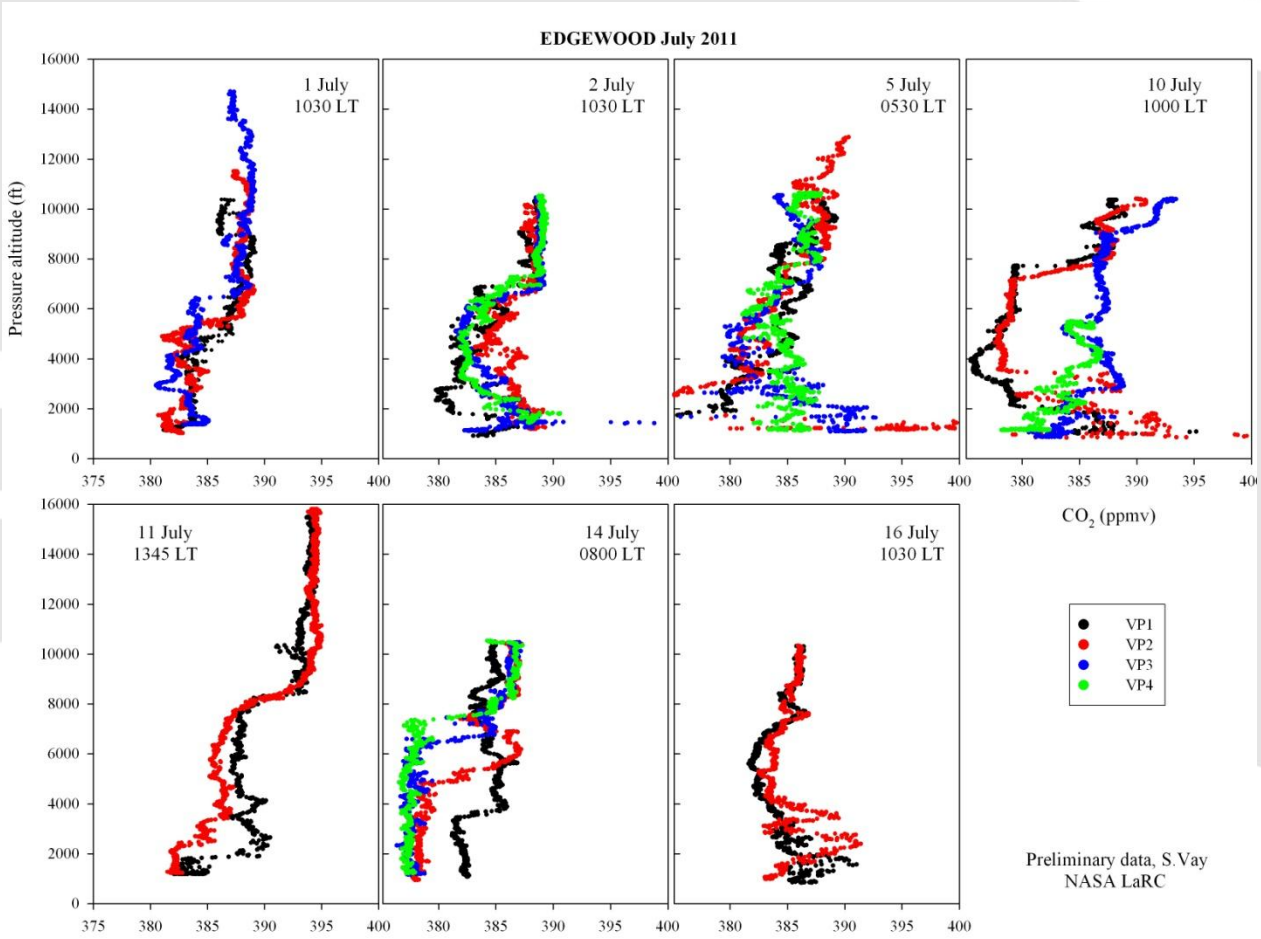
Airborne HSRL Measurements of Aerosol Extinction over Baltimore-Washington DC Region



- LaRC HSRL deployed on NASA/LaRC UC-12
- High values of aerosol extinction were measured on this flight
- Highest values of extinction were observed about 2 km above the surface
- The high values of aerosol extinction were associated with aerosol hygroscopic growth due to high

Profiles of CO_2 Measured from the P-3B

- Wide range of variability over short temporal and spatial scales
- Column variability in both the boundary layer and free troposphere
- Variability driven by both source and sink processes



COMMERCIAL SUBORBITAL

- Why Commercial Suborbital?
  - Affordable opportunity to make brief/local (but perhaps frequent) measurements from above the atmosphere (looking outward, or integrating downward)
  - Allows for rapid inter-flight refinement and retest – affordable iterative development
  - Enables brief demonstrations of instruments in the environment of space

- Issues to be considered – downward-looking
  - Limited spatial-temporal extent of flights – one geographical location, minutes per flight separated by
  - Requires phenomenon to be short-duration, predictable (or continuous), spatially extensive; sampling theorem and aliasing must be considered for multiple flights
  - Difficult to accomplish in-situ sampling
  - Complementarity with airborne platforms

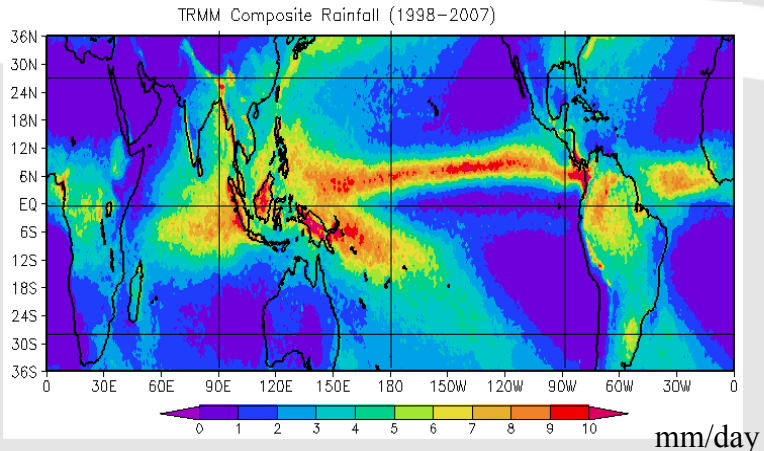
Proposal Approach (personal)

- Define clear science focus
- Justify sampling, coverage afforded by Commercial Suborbital
- Justify cost relative to benefits

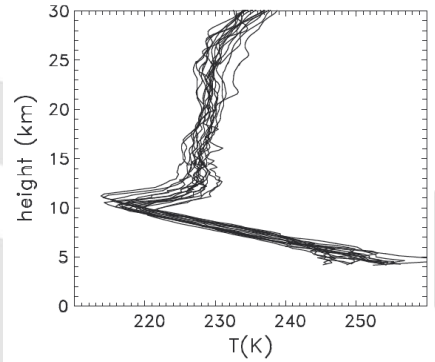
- Technology development/demonstration
- “Outward-looking” processes probably most fruitful in near-term
- Innovative calibration, monitoring (TSI?)

BACKUP

Satellite-Enabled Insights: Climatology and Process Knowledge

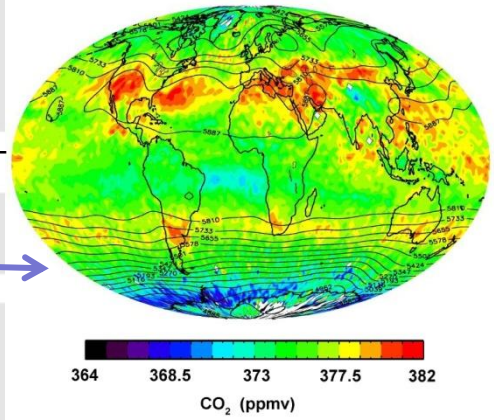


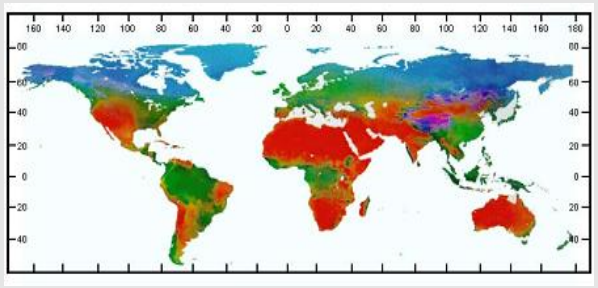
TRMM data provide climatology of tropical precipitation



COSMIC data provide new insights into polar summer tropopause inversion layer

AIRS data enable calculation of mid-tropospheric CO_2 climatology (7/03)



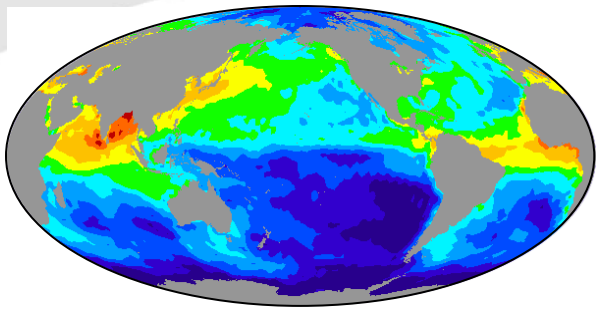


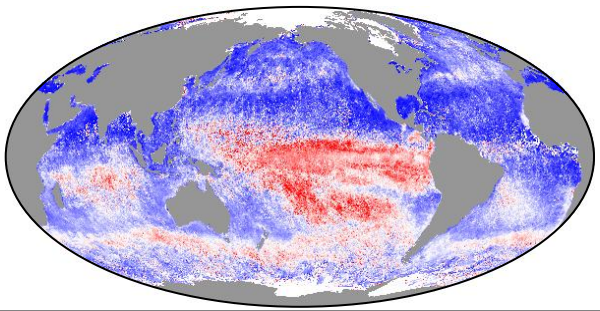
Soil Moisture

Freeze/ Thaw

Radiation

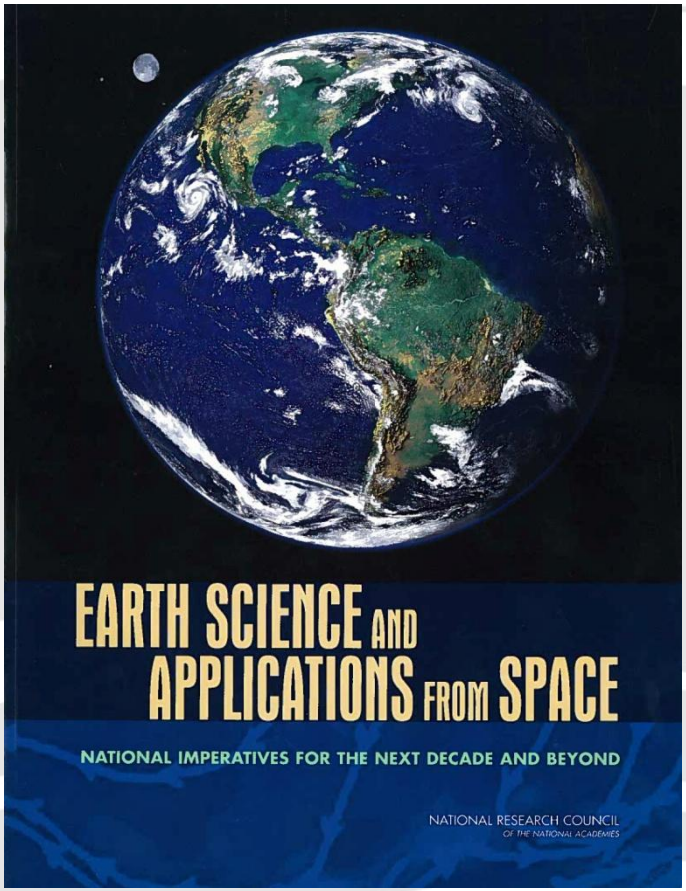
Primary controls on land evaporation and biosphere primary productivity





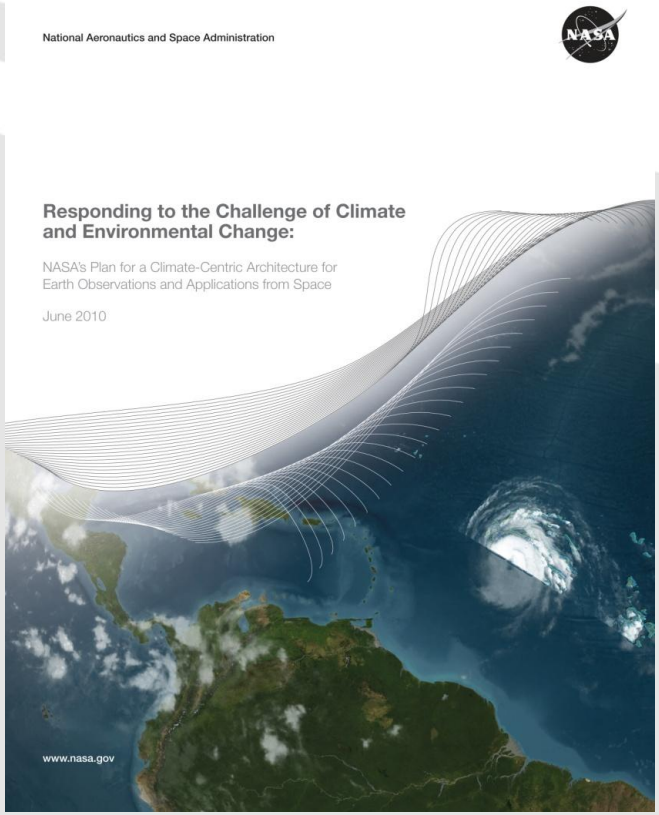
MODIS fluorescence data show regions of iron stress

Guiding Recommendation Documents



Administration priorities and constraints

Decadal survey,
OCO-2,
climate continuity missions,
balanced program
Integrated Program



2007 Decadal Survey

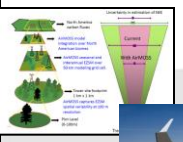
- Research and Applications communities priorities
- No realistic budget constraint (calls for $2B funding [FY06 constant $$ beginning in FY10)

http://science.nasa.gov/media/medialibrary/2010/07/01/Climate_Architecture_Final.pdf

- Dec Surv + Administration priorities
- Executable for FY11 Pres. Bud.
- OSTP, USGCRP, OMB approval

Earth Venture-1

Summaries

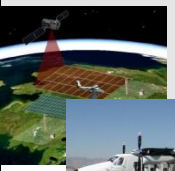



Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) - Univ Mich/JPL

North American ecosystems are critical components of the global exchange of the greenhouse gas carbon dioxide and other gases within the atmosphere. To better understand the size of this exchange on a continental scale, this investigation addresses the uncertainties in existing estimates by measuring soil moisture in the root zone of representative regions of major North American ecosystems. Investigators will use NASA's Gulfstream-III aircraft to fly synthetic aperture radar that can penetrate vegetation and soil to depths of several feet.


Airborne Tropical Tropopause Experiment (ATTREX) - ARC

Water vapor in the stratosphere has a large impact on Earth's climate, the ozone layer and how much solar energy the Earth retains. To improve our understanding of the processes that control the flow of atmospheric gases into this region, investigators will launch four airborne campaigns with NASA's Global Hawk remotely piloted aerial systems. The flights will study chemical and physical processes at different times of year from bases in California, Guam, Hawaii and Australia.

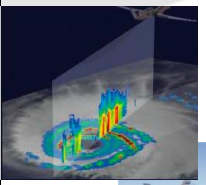



Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) - JPL

This investigation will collect an integrated set of data that will provide unprecedented experimental insights into Arctic carbon cycling, especially the release of the important greenhouse gases such as carbon dioxide and methane. Instruments will be flown on a Twin Otter aircraft to produce the first simultaneous measurements of surface characteristics that control carbon emissions and key atmospheric gases.


Deriving Information on Surface Conditions from COlumn and VERtically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) - LaRC

The overarching objective of the DISCOVER-AQ investigation is to improve the interpretation of satellite observations to diagnose near-surface conditions relating to air quality. NASA's B-200 and P-3B research aircraft will fly together to sample a column of the atmosphere over instrumented ground stations.




Hurricane and Severe Storm Sentinel (HS3) – GSFC/ARC

The prediction of the intensity of hurricanes is not as reliable as predictions of the location of hurricane landfall, in large part because of our poor understanding of the processes involved in intensity change. This investigation focuses on studying hurricanes in the Atlantic Ocean basin using two NASA Global Hawks flying high above the storms for up to 30 hours. The Hawks will deploy from NASA's Wallops Flight Facility in Virginia during the 2012-14 Atlantic hurricane seasons.

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NON-FLIGHT RESEARCH AND APPLICATIONS ACTIVITIES

The FY2011 budget augmentation enables several key research, applications, technology, and education activities to be initiated or greatly expanded. These non-flight activities both enable the new space missions and provide the scientific and societal benefits from the spaceborne measurements.

- Modeling, assessment, and computing activities to expand NASA's contribution to the 2013 National Assessment by the USGCRP and the next mitigation and adaptation (Working Group II) assessment of the IPCC;
- Acceleration of operational use of NASA research data to improve climate prediction and weather forecasting, including expansion of SERVIR to additional nodes in strategic locations in the developing world in collaboration with USAID, and expansion of the sources and types of information products available to and from SERVIR nodes;
- Synthesis of NASA Earth Science observations via expanded opportunities for competitively-selected Interdisciplinary Science investigations and key mission science team work;
- Calibration of multi-satellite global data sets to enable increasing leverage of international data contributions, furthering the goals of USGEO and GEOSS;
- Development of NASA's contributions to a national Carbon Monitoring System in collaboration with other federal agencies;
- Expanded Earth Science Technology Program to provide the technology advances needed to enable accelerated implementation of Decadal Survey Tier 2 & 3 missions;
- Commensurate investment in Earth Science education programs such as GLOBE to assure that new Earth science understanding is infused in the nation's education curricula and that an educated workforce and populace is equipped to use the results of NASA's Earth Science program.

Integrated Program for Water Availability/Quality

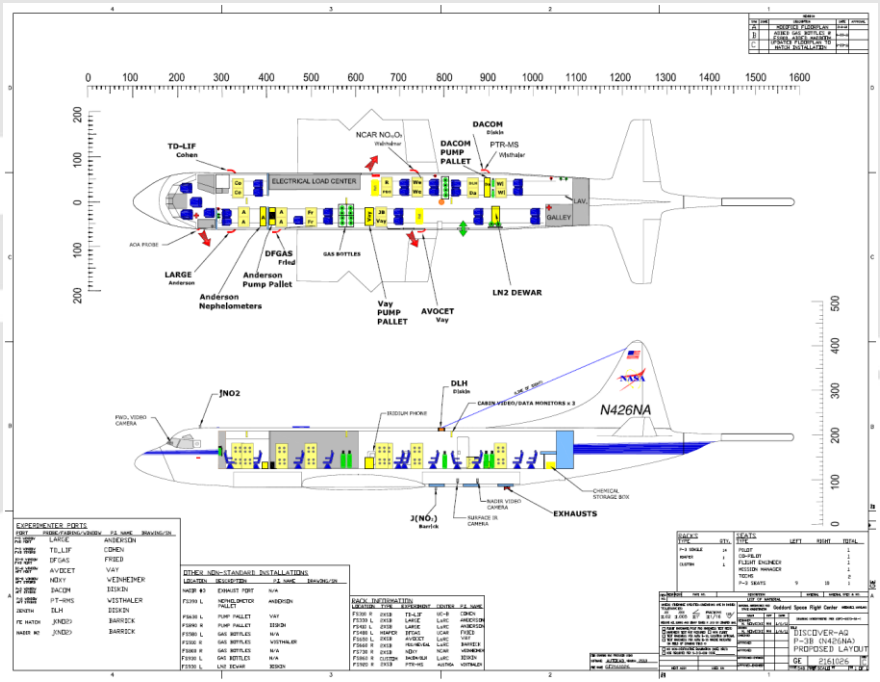
- Precipitation
  - TRMM (extended mission w/JAXA); Field Campaigns (e.g. GRIP, EV-1 Hurr. & Severe Storm Sentinel [HS3]); GPM (7/2013 w/ JAXA)
- Soil Moisture and Freeze/Thaw State
  - SMAP (5/2015 w/CSA)
- Inland Waters
  - SWOT (late 2019 w/CNES, CSA)
- Subsurface Ground Water (Aquifer Volume Changes)
  - GRACE (extended mission w/ Germany); GRACE-FO (2016 w/ Germany)
- Glacier and Ice Sheet Volume Changes and Dynamics
  - ICEBRIDGE (ongoing); ICESAT-2 (2016); DESDynI ~~(2017)~~
- Coastal Water Quality
  - PACE (2019/2020 w/ CNES [likely])
- Northern Latitude Land, Lakes, Permafrost
  - EV-1 CARVE, SMAP, SWOT, GRACE-FO, ICESAT-2, DESDynI
- Accelerated Operational Use of Research Measurements, …

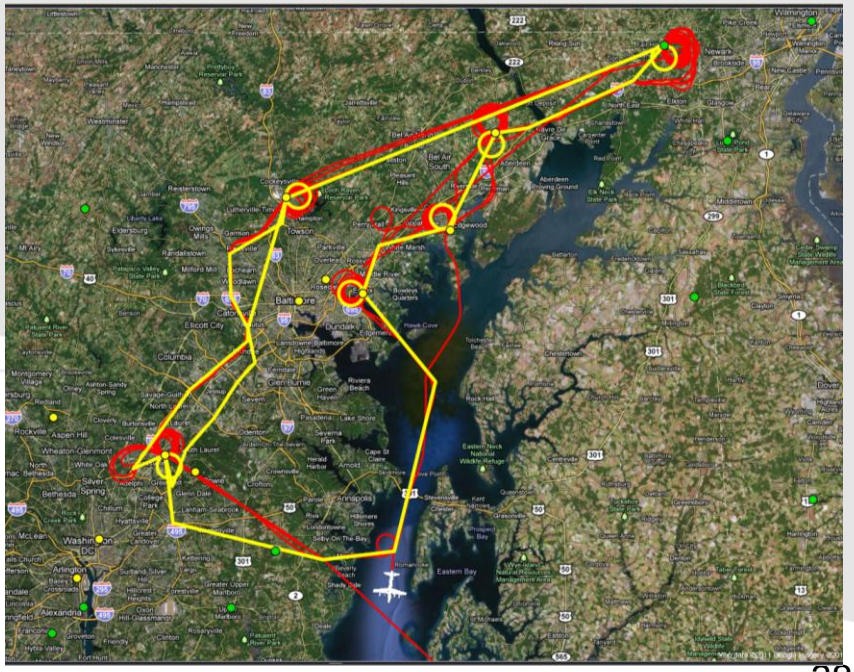
Integrated Carbon Cycle Research, Monitoring, Products

- Based on existing Carbon Cycle and Ecosystem R&A Focus Area
- Global Measurements of Atmospheric CO2
  - OCO-2 (2/2013)
  - OCO-3 (2015; instrument for flight of opportunity)
  - ASCENDS (2019-2020)
- Global Measurements of Terrestrial Aboveground Biomass
  - ICESAT-2 (2016; supporting lidar measurements)
  - ~~DESDynI radar/lidar (2017)~~
- Global Measurements of Oceanic Productivity
  - VIIRS(?) (2011/NPP, 2015??/JPSS)
  - PACE (2019; ocean-optimized radiometry, polarimeter)
- Development, Evaluation, and Evolution of Observationally-Based Carbon Products
  - Sustained Pilot Projects

P-3 Missions – DISCOVER-AQ

- DISCOVER –AQ: Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality
- 4 year campaign to measure air quality and related processes over major U.S. cities (DC/Baltimore, Sacramento, Houston, Birmingham/Atlanta)
  - Resolve diurnal cycle; vertical profiling; satellite validation; in situ sampling; remote sensing
- 9 instruments on P-3 (aerosol probes and lasers)
- Coordinated flights with LaRC B-200 and other contracted aircraft
- P-3 mission flights 7/1-31; aircraft download 8/1-5





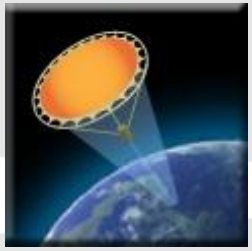
Earth Science Technology:
Program Elements

The *Earth Science Technology Office (ESTO)* is a ***targeted, science-driven, competed, actively managed, and dynamically communicated technology program*** and serves as a model for technology development.

Competitive, peer-reviewed proposals enable selection of best-of-class technology investments that ***retire risk*** before major dollars are invested: a cost-effective approach to technology development and validation.

ESTO investment elements include:

Observation Technologies:



Instrument Incubator Program (IIP)
provides robust new instruments and measurement techniques

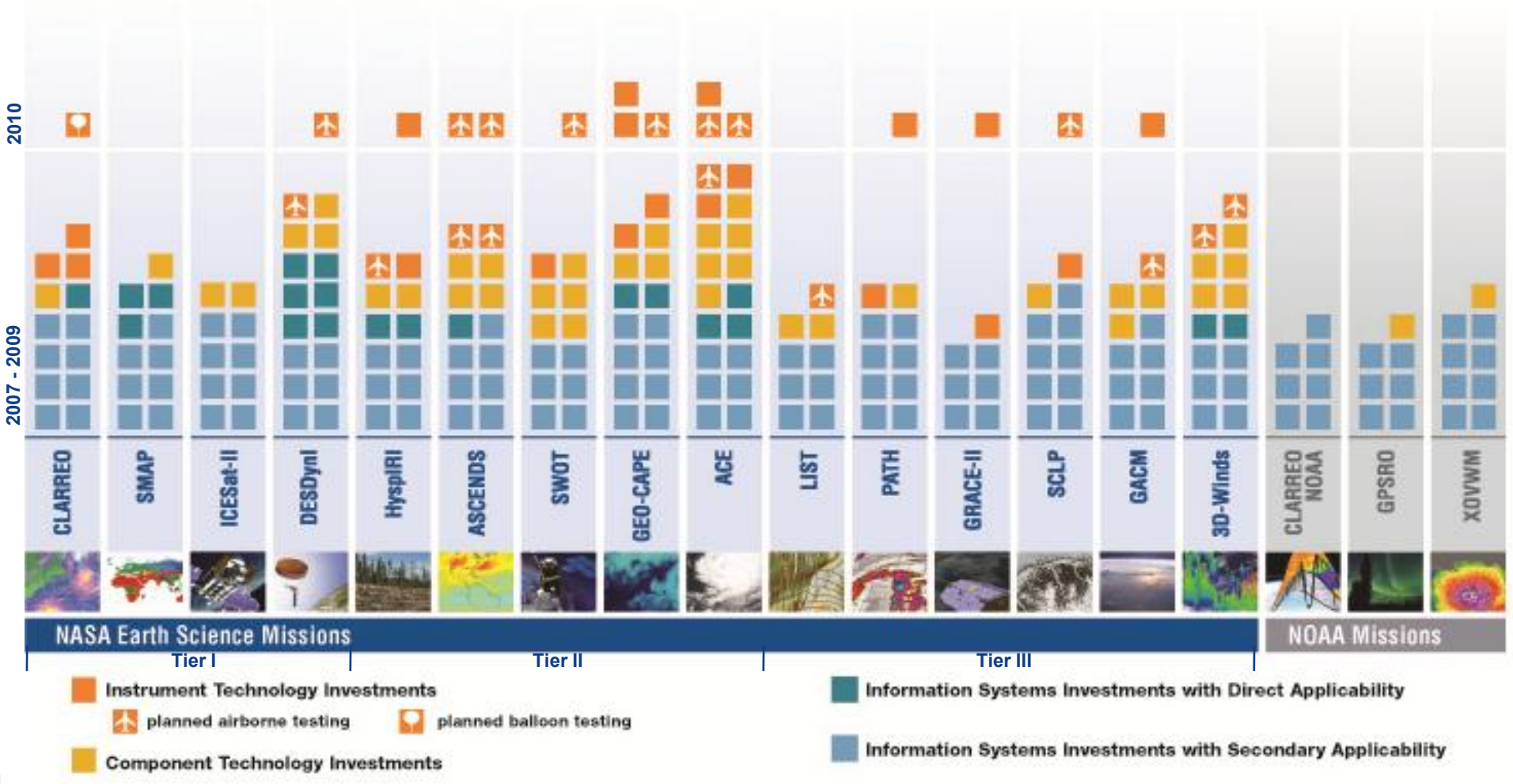
Advanced Component Technologies (ACT)
provides development of critical component and subsystem technologies for instruments and platforms

Information Technologies:

Advanced Information Systems Technology (AIST)
provides innovative on-orbit and ground capabilities for communication, processing, and management of remotely sensed data and the efficient generation of data products and knowledge

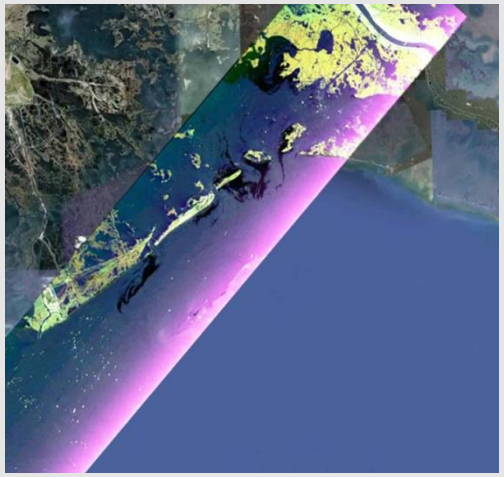
Earth Science Technology:
New Investments Enabling the Decadal Survey

Upon publication of the Earth Science Decadal Survey in 2007, ESTO investments **already supported all 18 of the recommended mission concepts**. Since then, ESTO has awarded **74** additional technology projects representing an investment of ***over $172M directly related to the Earth Science priorities outlined by the Decadal Survey.***

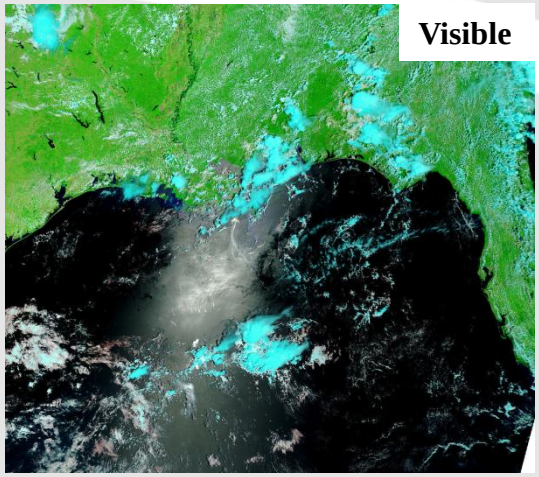


NASA Response to Gulf Oil Spill

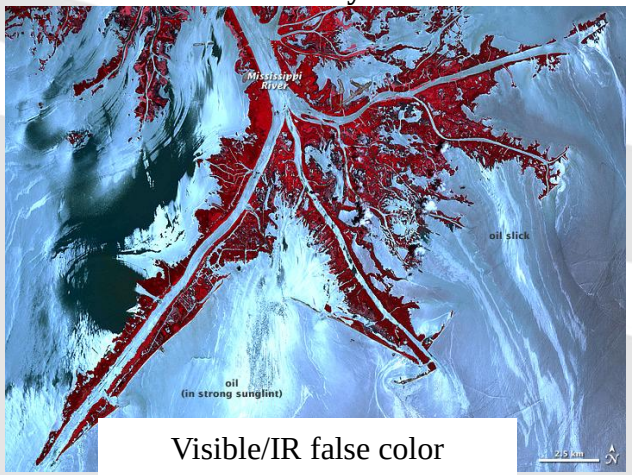
UAVSAR 23 June 2010



MODIS 31 May 2010



ASTER 24 May 2010



Visible/IR false color

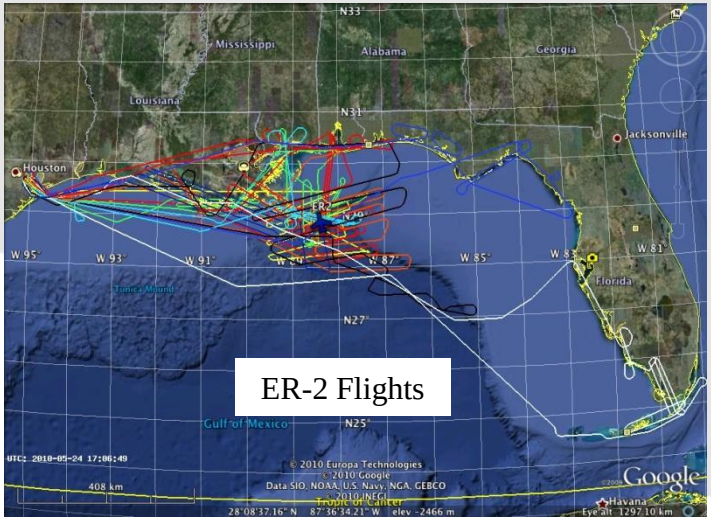
Satellite instruments: continually monitored the "extent"of the spill

- Terra & Aqua / MODIS – visible and infrared daily synoptic
- Terra / ASTER – visible, near IR and thermal IR high res
- EO-1 / Advanced Land Imager and Hyperion – highest res
- Terra / MISR
- CALIPSO / CALIOP

Airborne instruments: measuring *surface* extent and volume

- ER2 / AVIRIS and DCS: **18 sorties, >120 flight hours**
- Twin Otter / AVIRIS: **32 sorties, 107 flight hours**
- B200 / HSRL: **5 sorties, 16 flight hours**
- UAVSAR: 22-24 June, **4 sorties, 21 flight hours**

Data and provided to USGS for use by first responders; NOAA used radiances to initialize trajectory model; USGS for oil concentration



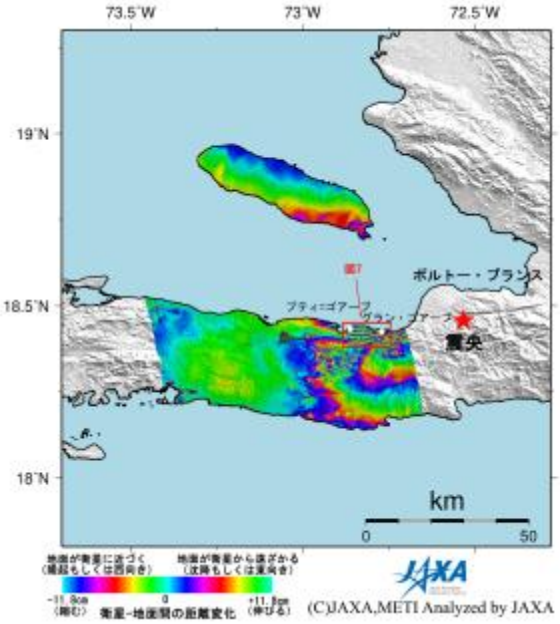
ER-2 Flights

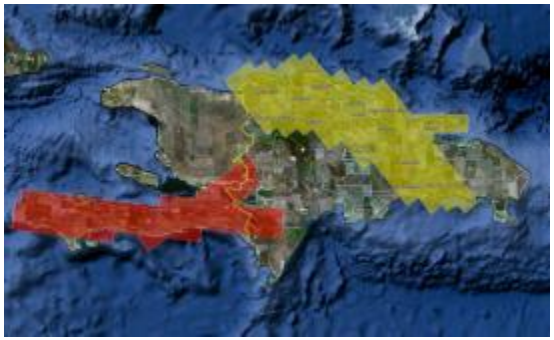
UAVSAR Measures Deformation of Hispaniola Faults

Following the devastating Haiti Earthquake

NASA added a series of science over-flights of earthquake faults in Haiti and the Dominican Republic on the island of Hispaniola to a previously scheduled three-week airborne radar campaign to Central America, Jan 25- Feb 14 to study the structure of tropical forests; monitor volcanic deformation and volcano processes; and examine Mayan archeology sites.

Above: Quicklook Image along the Enriquillo-Plantain Garden Fault showing only half the acquired range swath: Acquired on January 27, 2010





NASA's UAVSAR airborne radar created 3-D maps of earthquake faults over wide swaths of Haiti (red shaded area map left) to study post-seismic deformation; and the Dominican Republic (yellow shaded area) to baseline the historically very active fault.

Current international spaceborne SAR provides examples of the opportunity, but do not image regions at risk to geohazards on a systematic global basis. Image on the left : JAXA ALOS PALSAR demonstrates L-band coherence over a 10-month period to observe deformation in Haiti, but typically there are only 1-2 observations / yr with a 46-day revisit possible. UAVSAR supplements temporal coverage, provides higher resolution and optimized viewing geometry.

SMD/ESD Applied Sciences Program

Program Strategy

Goal 1: Develop Applications

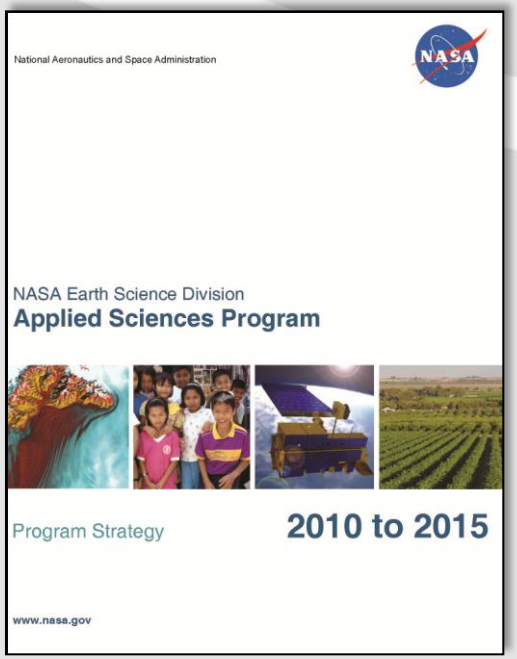
Identify priority needs, conduct applied research to generate innovative applications, and support projects that demonstrate uses of NASA Earth science.

Goal 2: Increase Collaboration

Pursue partnerships to leverage resources and risks and extend the program's reach and sustained impact.

Goal 3: Integrate Applications Potential in Mission Planning and Execution

Identify applications early in mission lifecycle and facilitate effective ways to integrate end-user needs into satellite mission planning.

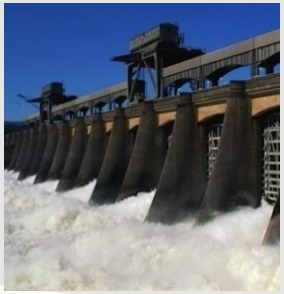


AppliedSciences.NASA.gov

Applied Sciences Program
Applications Areas (USGEO 9 SBAs)

Emphasis in 4 Applications Areas

Health
(incl. Air Quality)



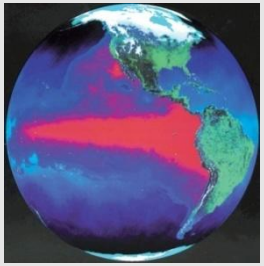
Water
Resources

Disasters

Ecosystems

Seek opportunities to expand to 5 additional areas

Agriculture



Climate

Weather

Energy

Oceans

GloPac Arctic Flight Track (4/22-4/23, 28 – 30 hours)

Artic sampling flight

Flight time = 28-30

Distance ~ 8400 nmi